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TRAY MATERIALS IN RELATION TO SULFITED, DEHYDRATED VEGETABLES

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The recent introduction of a sulfiting step in the preparation of shredded cabbage for dehydration has caused some concern over possible corrosion difficulties. Since galvanized-wire-mesh drying trays would be expected to show the effects of corrosion more markedly than other parts of the equipment, experiments have been conducted in which the rate of attack on the zinc coating of galvanized trays under simulated commercial conditions was measured. It was found that the rate of loss of zinc is not greatly different whether the sulfite pretreatment is used or not. Unsulfited cabbage and potatoes were found to be more corrosive to zinc than carrots. The corrosion caused by either unsulfited or sulfited carrots is an insignificant factor in the life of galvanized trays.

Trays represent a considerable continuing cost to a dehydration plant. The common 3x6-foot tray, with wood frame and wood slat or galvanized wire mesh bottom, ranges in cost from $1.50 to about $4.00; all-metal trays, usually smaller in size, cost even more per square foot of area. A 100-ton plant may use from 2,000 to 4,000 of the 3x6-foot trays, and their life is commonly considered to be not over 1-1/2 to 2 years. Any marked shortening of this life would be reflected in a perceptible increase in the cost of the dehydrated product. Trays rather than other parts of the equipment were selected for a study of corrosion because the metal of trays is exposed to a severe combination of conditions, including wetness of surface, high temperature, and presence of air.

Effect of Sulfites on Wood, Tin, and Zinc

Wood withstands strong, cold, sodium acid sulfite solutions well and it is a satisfactory tank material for sulfite solutions. In fact, it is softened only slightly by boiling for 8 hours in a 25 percent solution of sodium acid sulfite. Therefore, sulfiting will probably not exert a measurable influence on the life of wood trays or of wood frames. Nails used should be galvanized and should be clinched.

Tinned wire of the type obtainable under wartime restriction does not make a serviceable wire-mesh tray bottom. Such wire is only lightly tinned before it is woven, and rusting of the underlying steel occurs almost at once under service conditions. Furthermore, when samples of this kind of screen were immersed in hot, dilute sulfite solutions a black corrosion product formed quickly. Other tests showed that cabbage dried on rusty, tinned wire mesh was stained black. Heavy tin coats, especially if applied after the screen has been woven, would be more durable, but are not obtainable now except to re-coat tinned trays made before May 25, 1943 (Conservation Order M-81). In contrast to worn tinned screen, that made of galvanized steel wire does not stain cabbage during the drying step, even though the steel becomes exposed. Instead, the steel remains bright as long as some zinc coating remains.

Experimental Corrosion of Galvanized Wire Mesh

Cabbage. Experiments carried out in complete operating cycles with unsulfited cabbage indicated that, apart from mechanical wear, the galvanized coating might last during 6 months of continuous use. The test screen used (having 5 meshes to the inch) was made from 23-gauge steel wire, galvanized after weaving with 3 ounces of zinc per square foot. Estimated lives of coatings are based on 2.1 oz. of zinc per sq.ft., a more common weight than 3 oz. for this purpose (Table 1).

In estimating the life of zinc coatings the zinc was assumed to be present as a uniform cylindrical sheath over the iron wire in the screen. Measurements of the wire diameters were made with a traveling micrometer before and after the galvanizing was chemically removed from the iron wire. The thickness of the coating was then calculated as half of the mean difference between the two diameters. Measurements of corrosion were based on the weight loss per sample of screen per cycle under various experimental conditions. These weight losses were converted to inches of penetration per month of 60 operating cycles. The estimated life was then computed by division of the thickness of coating by the inches of penetration per month.

Table 1 1/. Corrosion of Galvanized Screen Bottom Trays While Dehydrating Cabbage

Spray			Penetration 2/	Estimated
Acidity as pH	Total SO_2 (%)	Added coating	(Inches per month x 10^6)	life of zinc (mo.)
	None	None	460 ± 120	6
6.7	0.25	None	120 ± 20	25
7.6 - 8	0.25	None	370 ± 120	8
7.6 - 8	0.25	Oil	270 ± 70	10
7.6 - 8	0.25	Wax	140 ± 100	20

1/ The results reported here and in other tables are based on statistically treated data derived in every case from 6 to 10 complete operating cycles.

2/ Penetrations in Tables 1 to 5 are based on two complete cycles every 24 hours and on a galvanized coating of 2.1 oz. per sq.ft.

The first sulfiting test shown in this table was conducted with a one-to-one sulfite-bisulfite solution containing 0.25 percent total SO_2. The pH of this solution was 6.7. In the other three sulfiting tests the solution contained a higher proportion of the slightly alkaline normal sulfite than of the bisulfite.

While rather large experimental variations are shown by the data in Table 1, it may be concluded that the use of sulfites on cabbage actually diminishes somewhat the rate of corrosion of the galvanizing, rather than accelerating it. The "Estimated life" given in the last column must be regarded only as approximate. The figures correspond reasonably well, however, with the known practical life of screen trays.

The lower rate of attack on the zinc when the more acid sulfite solution (pH 6.7) was used was unexpected, since preliminary experiments had indicated a progressive increase in the corrosiveness of sulfite solutions to zinc as the pH was

lowered, the zinc being continuously immersed in the solution at 140° F. A second series of complete blanching and drying experiments was accordingly made. The pH of the sulfite solution, containing 0.25 percent total SO_2, was varied over a wider range, 5.2 to 9.5. The results are given in Table 2.

Table 2. The Relationship of pH Value of Sulfite Spray Solution to the Corrosion of Galvanized Screen

Sulfite spray pH	SO_2 Retention after drying (ppm.)	Wilting on trays 1/ (%)	Pitting factor 2/	Penetration rate (inches per month x 10^6)	Estimated life of zinc (mos.)
5.2	3870 ± 50	45 ± 0.5	5 ± 2	97 ± 5	28
6.7	3900 ± 120	44 ± 0.9	3 ± 2	106 ± 10	26
8.0	5300 ± 170	46 ± 0.8	10 ± 2	166 ± 16	16
9.5	5100 ± 130	49 ± 1.3	16 ± 2	187 ± 17	15

1/ The amount by which the depth of cabbage on the tray decreased upon blanching and sulfiting, expressed as a percentage of the maximum attainable shrinkage in depth.

2/ The increase in average number of pits per square inch of screen in 4 complete cycles; the average count on the original screen was 42 per sq. in.

The use of slightly alkaline solutions, pH 8 and 9.5, resulted in a significantly higher rate of corrosion, confirming the earlier findings, although the rate at pH 8 was not as high as it was in the first series. The uptake of SO_2 in the dried product, shown in the 2nd column of Table 2, is far above the level required by current Government specifications (750-1500 ppm.). In view of the corrosion-inhibiting action of sulfite, evident from the first series of experiments, it may be assumed that at the specification level the rate of attack would have been somewhat higher, more nearly equal to that of unsulfited cabbage.

At the end of the corrosion experiments the conspicuous holes and corrosion pits in the galvanizing of the screen samples were counted. The numbers of pits on screen exposed to sulfite solutions at pH 5.2 and 6.3 were not significantly different from the count on the blank, but the counts for pH 8 and 9.5 were both definitely greater.

The extent of wilting of the cabbage due to blanching and spraying (defined in a footnote to Table 2) was found to increase from 45 to 49 percent with a change of pH from 5.2 to 9.5. This rather small increase in wilting was measured with sufficient accuracy to indicate a definite trend. It is hypothesized that part of the increased corrosion at the higher pH values was due to an increased contact area of the cabbage with the screen, and partly to other causes.

A number of previous observers have stated that the color of dehydrated sulfited cabbage is greener as the pH of the sulfite solution is increased; this effect was also noted in the present series of experiments. The juice of unsulfited, blanched cabbage is somewhat acid, the pH being 5.4. When sulfited with a sulfite solution of pH 8 in the blancher, the acidity of the cabbage juice was reduced, the pH rising to 6.9. Cabbage which had been sulfited in the blancher with a solution at pH 6.7 showed a pH value afterward of 6.4 to 6.5.

Equipment corrosion is only one of several factors that should be weighed in arriving at the proper pH level to maintain in the sulfite solution. The color and texture of the product, the rapidity of oxidation of solution in the storage tanks, and possibly the relation between solution concentration and SO_2 uptake in the cabbage are all affected by a change in pH. Fortunately, neither these factors nor the rates of corrosion of the equipment appear to require very precise control of pH if the latter is within the range of about 6.5 to 8. Mixtures of equal parts of normal sodium sulfite (Na_2SO_3) and sodium metabisulfite ($Na_2S_2O_5$) (pH 6.7), and of eight parts of the former with one of the latter (pH 8.0) have both been successfully used in commercial plants. From the standpoint of corrosion alone it would be advisable to use the slightly acid solution if tray corrosion alone is likely to be serious, or the slightly alkaline solution if the trays give less concern than conveyors, the blancher body, or other metal parts that would be kept wet with the solution.

Potatoes. Klamath potatoes were cut julienne style, sulfited in the blancher, and transferred to galvanized mesh-bottom trays for drying. The solution, containing 0.4 percent total SO_2, was made with 20 parts of sodium sulfite to one part of bisulfite (pH 8.1-8.3) (Table 3).

Table 3. Corrosion of Galvanized Screen Bottom Trays While Dehydrating Potatoes

Sulfite spray pH	Total SO_2 (%)	Added coating	Penetration rate (Inches per month x 10^6)	Estimated life of zinc (mos.)
--	None	None	30 ± 6	10
8.1-8.3	0.40-0.43	None	57 ± 20	5
8.1-8.3	0.40-0.43	Lacquer-oil	15 ± 5	20
8.1-8.3	0.40-0.43	Wax	10 ± 4	30

The experimental uncertainty of the results in the first two lines of Table 3 is so high that the difference in penetration rates (and in the corresponding lengths of life of the galvanizing) for sulfited and unsulfited potatoes on uncoated trays is not statistically significant. The rate of corrosion is of about the same magnitude as that with unsulfited cabbage. In this series of runs the uptake of SO_2 by the potatoes was undoubtedly far above the level tentatively required by Government contracts.

A second series of runs was made with julienne-cut potatoes to evaluate the influence of pH value on the corrosion of the galvanized screens. The potatoes were steam blanched and sulfited in the blancher with solutions containing 0.10 percent total SO_2, and at pH 5.3, 6.7, and 8.0. They were not washed prior to drying (Table 4).

Table 4. The Relationship of pH Values of Sulfite Solutions to the Corrosion of Galvanized Screen During Dehydration

Sulfite spray pH	SO_2 retention after drying (ppm.)	Penetration rate (inches per month x 10^6)	Estimated life of zinc (mos.)
5.3	230 ± 10	130 ± 3	21
6.7	270 ± 50	162 ± 4	17
8.0	270 ± 30	142 ± 4	19

The rate of corrosion of the zinc-coated screens was essentially the same for all three levels of pH. Attack was significantly slower than in the first series, possibly because of a difference in the corrosiveness of the samples of potatoes used at the two times, several months apart. The sulfite concentrations in the dried product closely approximated those specified in Government purchase contracts.

So far as the corrosion of the trays is concerned, operators should feel free to use sulfite solutions of any pH value within the range of Table 4. Solutions made with equal parts by weight of normal sodium sulfite and sodium metabisulfite will probably be suitable in all respects. If the blancher, or other equipment which is wet by sulfite solution, is strongly attacked, it would be worth while to test the effect of a somewhat more alkaline solution. Too high an alkalinity should be avoided, however, since it will result in a mushiness of the potatoes.

Carrots. Diced carrots were sulfited in the blancher with a one-to-one sulfite-bisulfite solution containing 0.12 percent total SO_2. This solution had a pH value of 6.7 (Table 5).

Table 5. Corrosion of Screens While Dehydrating Carrots

Sulfite spray			Penetration rate	Estimated
pH	Total SO_2 (%)	Added coating	(inches per month x 10^6)	life of zinc (mos.)
--	None	None	15 ± 9	200
6.7-6.8	0.12	None	40 ± 8	70

Fresh carrot juice was found to have a pH value of 6.5, essentially the same as that of the sulfiting solution. The galvanized drying trays were attacked over twice as fast when sulfite was used, but nevertheless the estimated life of the galvanized coating with respect to corrosion was more than 5 years. Zinc-coated screen trays used for the dehydration of carrots will fail from mechanical wear, it appears, and not from corrosion.

Effect of Oil and Wax Coatings

White mineral oils of U.S.P. grade or water emulsions of waxes with resins are being used in many plants to diminish the adhesion of the dried products to the trays. The oil or emulsion is applied to the tray surface periodically by spray, brush, or dip. A seven-day interval between treatments is common. Some dehydrators oil the trays daily, or even on every trip, using a very attenuated oil spray above the tray conveyor.

Oil or wax coatings produce surfaces from which dehydrated, sulfited cabbage is removed much more readily than from freshly cleaned surfaces. The life of the trays is probably lengthened because less vigorous pounding and scraping are necessary to empty them. However, this pretreatment does not eliminate the necessity for some scraping when the oil or wax is used in commercially feasible amounts. Julienne-cut potatoes, dried on an uncoated tray, separate more easily from the tray than cabbage does; under experimental conditions all but about 1 percent of the dry potato was removed by a moderate, measured blow, leaving

0.04 oz. per square foot stuck to the wire. Under the same conditions, but with oil or wax coatings, only 1/2 percent of the load of potatoes was left on the trays, or 0.02 oz. per square foot, so that scraping was barely necessary to prevent defects due to twice-dried pieces. This is in agreement with commercial results. Incidentally, it was noted that when a tray was lacquered, but not oiled, the amount of sticking increased substantially.

Tables 1 and 3 include data on rates of tray corrosion from experimental runs in which white oil or wax emulsion was applied to the tray surface. Only one application was given before the series of 6 complete drying cycles was begun. Some diminution in the rate of corrosion was found in all cases.

Zinc Content of Foods Before and After Sulfiting

Some foodstuffs cannot be used in contact with zinc or galvanized equipment because they attack it too rapidly, resulting in a high and unsafe zinc content in the food. The total zinc intake in all the foods eaten would be the controlling factor in zinc poisoning. Consequently, expert opinion varies as to permissible limits for the zinc in any one product. R. H. Morgan and H. W. Rawlings[1] have suggested 100 parts per million for the limit in any foodstuff.

The natural zinc content in dehydrated cabbage is considerable, about 50 ppm. (Table 6). However, on the rehydrated basis, which would be more significant, the zinc content would be far below the limit suggested by Morgan and Rawlings (Table 7). As would be expected, no significant increase in zinc content occurred when cabbage was dehydrated on wooden trays. Cabbage dehydrated on galvanized trays, then rehydrated to 8.5 times its dry weight, contained about 50 to 100 ppm. of zinc, or almost the suggested limit; the result was very nearly the same, whether the cabbage was sulfited or not. The zinc content of the chemicals used for sulfiting was negligible. The zinc pickup by the cabbage was 10 to 15 percent of the zinc lost from the screen bottoms of the galvanized trays.

Table 6. Zinc Content of Raw, Unprocessed Vegetables

Vegetable	Zinc content: Raw (ppm.)	Dry basis (ppm.)	Rehydrated basis[1] (ppm.)
Cabbage	4.5	50	6
Potatoes	1.5-3	8-15	2-4
Carrots	4	30	5

1/ Rehydration ratios taken from "Cooking Dehydrated Foods," TM 10-406, War Department Tentative Manual, 22 November, 1943, as follows: Cabbage, 8.5 to 1; Potatoes, 3.6 to 1; Carrots, 6 to 1.

1/ Morgan, R. H., and Rawlings, H. W. Food 12, 144-7, 175-7, 186, (1943). Through Chemical Abstracts 38, 1035 (1944).

Table 7. Zinc Content of Sulfited, Dehydrated Vegetables

Vegetable	Tray material	Coating	Sulfite spray pH	Sulfite spray Total SO_2 (%)	Zinc content Dry basis (ppm.)	Zinc content Rehydrated basis (ppm.)
Cabbage	Wood	--	7.6-8	0.25	60	7
"	Galv. mesh	--	--	None	400-900	50-100
"	" "	--	7.6-8	0.25	400-800	50-100
Potatoes	Galv. mesh	--	--	None	230-320	60-90
"	" "	--	8.1-8.3	0.39	110-160	30-45
"	" "	Oil	8.1-8.3	0.39	70-170	20-45
"	" "	Wax	8.1-8.3	0.39	150-210	40-60
Carrots	Wood	--	--	None	39	7
"	Galv. mesh	--	--	None	70-220	12-35
"	" "	--	6.5-6.8	0.12	80-140	12-25

Sulfited dehydrated potatoes picked up less zinc than cabbage did. Pick-up was reduced somewhat by sulfiting the potatoes. The pick-up of zinc by carrots was similar to that for potatoes.

Conclusions

Corrosion of galvanized trays by the sulfite solutions commonly used is not a formidable problem. Cabbage and white potatoes are definitely corrosive to zinc, much more so than carrots. In experimental drying runs sulfiting led to no significant increases in the rate of tray corrosion, but actually decreased it under some conditions. The corrosion of galvanized trays by potatoes was markedly reduced by waxing or by the use of a lacquer coating plus oiling. Definite increases in the zinc content of dehydrated vegetables were found to occur when the vegetables were dried on galvanized trays. The amount of zinc picked up by the dry product corresponds to some 10-15 percent of the weight of zinc lost by the tray through corrosion, and tends to be somewhat lower in sulfited than in unsulfited vegetables. In neither case is the zinc content high enough to warrant concern from the food standpoint.

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